

*Seismic Assessment, Repair, and Rehabilitation of Existing Buildings.*  
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# **SEISMIC ASSESSMENT, REPAIR, AND REHABILITATION OF EXISTING BUILDINGS**

by

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## Abstract

When future earthquakes occur in the United States and Japan, the existing stock of earthquake hazardous buildings creates the potential for severe injury and loss of life as well as for enormous monetary losses, not only from direct property damage, but also from the indirect effects of slow down or elimination of economic activity in damaged structures. The recent earthquakes in Northridge, California (1994) and Kobe, Japan (1995), which caused monetary losses on the order of \$20 billion and \$200 billion, respectively, clearly demonstrate this loss potential.

Reducing seismic hazards posed by existing buildings is a multi-faceted problem that is concerned not only with mitigation efforts that should be initiated prior to damaging earthquakes, but also with mitigation measures that should be implemented following damaging earthquakes. The pre-earthquake efforts involve assessment and rehabilitation of undamaged hazardous buildings, whereas the post earthquake efforts involve assessment and repair of earthquake damaged buildings.

While both the United States and Japan have jointly conducted numerous activities related to the reduction of seismic hazards posed by existing buildings and while the United States has a well developed program to reduce such hazards, joint collaboration on and coordination of ongoing activities as well as needed new activities, and the interchange of ideas, information, and personnel would expedite efforts, improve efficiency, and eliminate costly duplication of effort. Five policy issues are recommended for inclusion in the U.S.-Japan Earthquake Disaster Mitigation Partnership:

Define mechanisms and public policies at the local community level to identify, evaluate, and rehabilitate earthquake hazardous buildings;

Using agreed-upon reporting and procedural standards, conduct laboratory cyclic testing of components and elements of existing buildings to determine dynamic stress-strain relationships and capacities;

Develop/improve engineering methods and standards of practice for the identification, evaluation, and rehabilitation of existing earthquake hazardous buildings;

Develop and test techniques for seismic rehabilitation of buildings that use new and emerging technologies, including light-weight, high-strength materials; and

Develop standards for evaluating and repairing earthquake damaged buildings so that their performance is improved in future earthquakes.

## I. Topic Description and Policy Issues

Since the devastating 1906 San Francisco and 1923 Tokyo earthquakes, which severely damaged thousands of dwellings and commercial and industrial buildings, both the United States and Japan have developed and implemented seismic design codes for new buildings. Over the years the codes have been updated on numerous occasions and have steadily improved building seismic performance. While today's seismic building codes are far from perfect, and indeed still need improvement, they have enabled the construction of buildings that are substantially safer than buildings designed without incorporation of seismic resistance features or in accordance with seismic codes that have proven to be inadequate. The fact remains, however, that there are tens, if not hundreds, of thousands of buildings in seismically active regions of both countries that are potentially earthquake hazardous. In the United States, potentially hazardous classes of buildings include unreinforced masonry buildings, non-ductile reinforced concrete frame buildings designed and constructed prior to about 1970, pre-cast concrete buildings, older concrete tilt-up buildings prior to about 1973, and recently designed and constructed steel moment frame buildings.

When future earthquakes occur in the United States and Japan, the existing stock of earthquake hazardous buildings creates the potential for severe injury and loss of life as well as for enormous monetary losses, not only from direct property damage, but also from the indirect effects of slow down or elimination of economic activity in damaged structures. The recent earthquakes in Northridge, California (1994) and Kobe, Japan (1995), which caused monetary losses on the order of \$20 billion and \$200 billion, respectively, clearly demonstrate this loss potential. Future similar events are expected, for example, in the Los Angeles basin, which is underlain with active hidden thrust faults that have the potential for causing magnitude 6.5 to 7.0+ earthquakes, and in the San Francisco Bay area, where Kobe-like events are likely to effect East Bay cities such as Oakland and Hayward.

The large stock of existing earthquake hazardous buildings in both countries gives rise to the following policy issues:

Reduction of direct and indirect losses from earthquake damaged buildings requires development and implementation of engineering methods and standards of practice for the identification, evaluation, and rehabilitation of earthquake hazardous buildings.

This requires (1) an understanding of the earthquake performance characteristics of existing buildings, (2) an understanding of the seismic hazards that are likely to affect buildings during their useful life, (3) programs to convert this knowledge into methods, techniques, and guidelines for building seismic assessment and rehabilitation that can be readily implemented by building design professionals and the construction industry, and (4) public policies at the local community level to encourage and enforce programs requiring seismic assessment and rehabilitation of existing buildings.

In addition, the reduction of earthquake losses in localities that are repeatedly affected by earthquakes requires the development and implementation of methods to evaluate and repair earthquake damaged buildings so that they perform better in future earthquakes

## II. Background

Reducing seismic hazards posed by existing buildings is a multi-faceted problem that is concerned not only with mitigation efforts that should be initiated prior to damaging earthquakes, but also with mitigation measures that should be implemented following damaging earthquakes. The pre-earthquake efforts involve assessment and rehabilitation of undamaged hazardous buildings, whereas the post earthquake efforts involve assessment and repair of earthquake damaged buildings.

The first step in pre-earthquake hazard mitigation is to conduct assessments of potentially hazardous buildings to determine if, in fact, they are hazardous. This requires an understanding of the seismic performance characteristics of existing buildings; an understanding of the seismic hazard exposure, including expected levels of earthquake ground shaking for given earthquake recurrence intervals and the potential for collateral hazards, such as liquefaction, fault rupture, and landslide; and systematic, consistent methods for evaluating the seismic strength of existing buildings. Once a building has been determined to be seismically hazardous, several options are available, including: (1) change the use of the building, (2) demolish the building, or (3) seismically rehabilitate the building, i.e., improve the seismic resistance of the building. Often the most economical and/or desirable option is to rehabilitate the building. This requires a knowledge of seismic strengthening techniques; an understanding of seismic performance characteristics of new and existing building components and their interaction; an understanding of the seismic hazard exposure; and systematic, consistent methods for seismic rehabilitation of buildings. Finally programs must be initiated at the local community level to ensure that seismically hazardous buildings are, in fact, evaluated and rehabilitated. The focus on local community programs stems from the well-recognized principle that "all mitigation is local" (FEMA, 1995).

Post-earthquake mitigation efforts involving the evaluation and repair of earthquake damaged buildings have requirements similar to pre-earthquake mitigation efforts: an understanding of building seismic performance characteristics and seismic hazard exposure, as well as systematic, consistent standards for the evaluation and repair of earthquake damaged buildings. Repair criteria must result in buildings that will have improved seismic resistance in comparison to their pre-damage condition.

U. S. Efforts. Over the last decade, the Federal Emergency Management Agency (FEMA) has devoted substantial effort and considerable resources on the development of a U. S. program to reduce seismic hazards of existing buildings. Results from the FEMA program include: a handbook for rapid visual screening of buildings for potential seismic hazards (ATC, 1988), a handbook for the seismic evaluation of existing buildings (BSSC, 1992a), techniques for seismic rehabilitation of buildings (BSSC, 1992b), two reports on typical costs for seismic strengthening, and a report on strengthening cost/benefit analysis. The capstone project in the FEMA program is

currently underway and involves the development of *Guidelines for the Seismic Rehabilitation of Buildings* (ATC, in preparation), which are scheduled for completion in September 1997. Developed by the Applied Technology Council (ATC) for the Building Seismic Safety Council (BSSC) with funding from FEMA, the *Guidelines* are intended to serve as a tool for design professionals, a reference document for building regulatory officials, and a foundation for the future development and implementation of building code provisions and standards. The *Guidelines* contain significant new features that are major departures from existing seismic codes for new buildings, including:

Criteria and methods for achieving owner/community selected performance levels for owner/community selected seismic hazard (ground shaking) level(s). Performance levels considered include collapse prevention, life-safety, immediate occupancy, and operational.

Methods for "Simplified Rehabilitation", applicable to small, regular buildings, primarily in areas of low and moderate seismicity, and methods for "Systematic Rehabilitation", complete procedures for considering all elements necessary to reach a specified performance level(s) for any building anywhere in the country for a selected seismic hazard level(s).

New state-of-the-art methods of analysis.

Since no new research was commissioned as part of the *Guidelines* developmental effort, much of the technical criteria and data are drawn from the results of recent research on the seismic performance characteristics of buildings and building components, and on quantification of the seismic shaking hazard. These results have come largely from earthquake engineering investigations sponsored by the National Science Foundation (NSF) and the National Institute of Standards and Technology (NIST), and from seismic hazard studies conducted by the U. S. Geological Survey (USGS) and NSF.

To date, there has been relatively little work in the United States relating to the development of engineering methods and standardized guidelines for the evaluation and repair of earthquake damaged buildings. FEMA is currently in the process of developing a project to assess the post-earthquake capacity of earthquake damaged reinforced concrete and reinforced masonry shear-wall and in-fill wall buildings. This project will rely on previous results from NSF- and NIST-funded research projects and may involve additional research. The FEMA project is presumably a first step in a larger effort that would be required to synthesize available research information and develop new information for estimating capacities of damaged wood, concrete, steel, and masonry structural elements of the type that would be found in typical buildings in seismically active regions of the United States. Such information is required before developing state-of-the-art technical guidelines for the evaluation and repair of earthquake damaged buildings.

Similarly, there has been relatively little work on the development of incentives and other policies for adoption at the local community level that will encourage implementation of seismic assessment and rehabilitation of existing buildings.

U. S. Needs. Recognizing that some of the technologies needed for reducing the seismic hazards posed by existing buildings have been developed, that new knowledge has been gained since the development of some of these technologies, and that there are technical areas requiring major advances, current U. S. needs include:

1. New knowledge about the seismic hazard and the seismic performance characteristics of steel moment frame and certain types classes of wood-frame buildings requires updating of the following U. S. technologies:

Methods for rapid visual screening of buildings for potential seismic hazards.

Methods for evaluating the seismic strength of existing buildings.

In addition, recognizing that life-safety has been the primary consideration in the development of these methodologies, consideration should be given to incorporation of criteria to consider damage control, which is currently explicitly not considered in these technologies.

2. Standardized protocol and additional laboratory tests are needed to develop information on cyclic stress-strain relationships and capacities of existing wood, steel, concrete, and masonry building components.

3. As new technology and information are developed, the following technologies should be updated:

*Guidelines for the Seismic Rehabilitation of Buildings*, particularly as new design approaches from expected investigations of performance based engineering and as new information from investigations of beam-column joints in steel moment frame buildings are completed (see companion paper by R. D. Hanson).

*Techniques for Seismic Rehabilitation of Buildings*, particularly as new technologies, including applications of new high-strength, light-weight materials, are developed, and as new information from investigations of beam-column joints in steel moment frame buildings are completed.

4. Comprehensive, state-of-the-art, nationally applicable, consensus-backed "Guidelines for the Evaluation and Repair of Earthquake Damaged Buildings" do not exist and should be prepared as soon as possible.

5. Mechanisms and public policies for implementation at the local community level to promote the identification, evaluation, and rehabilitation of earthquake hazardous buildings are needed.

U. S.-Japan Cooperative Efforts. Interaction between researchers and earthquake engineering practitioners from the United States and Japan has been ongoing for at least the last decade. Activities include: coordinated research on the seismic performance characteristics of existing reinforced concrete buildings; coordinated research on seismic isolation and passive energy

dissipation; workshops on urban seismic hazards, workshops on the improvement of structural design and construction practices, including methods and techniques for the seismic rehabilitation of buildings; and post-earthquake reconnaissance efforts to assess damaged buildings. Much of the U. S. involvement in these activities has been supported by the National Science Foundation. Some activities, such as the series of joint workshops that have been held every two years since 1984 by the Applied Technology Council and the Japan Structural Consultants Association, have been supported primarily with private funding.

### III. Proposal

While both the United States and Japan have jointly conducted numerous activities related to the reduction of seismic hazards posed by existing buildings and while the United States has a well developed program to reduce such hazards, joint collaboration on and coordination of ongoing activities as well as needed new activities, and the interchange of ideas, information, and personnel would expedite efforts, improve efficiency, and eliminate costly duplication of effort. Five policy issues that reflect the needs cited in the previous section are recommended for inclusion in the U.S.-Japan Earthquake Disaster Mitigation Partnership:

Define mechanisms and public policies at the local community level to identify, evaluate, and rehabilitate earthquake hazardous buildings:

Using agreed-upon reporting and procedural standards, conduct laboratory cyclic testing of components and elements of existing buildings to determine dynamic stress-strain relationships and capacities:

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Develop standards for evaluating and repairing earthquake damaged buildings so that their performance is improved in future earthquakes.

### IV. Cooperative Mechanisms

In general, the proposed activities could be coordinated under the auspices of the Wind and Seismic Effects Panel of the U. S.-Japan Program on Natural Resources (UJNR). In addition, federally funded collaboration amongst international scientific, technical and professional organizations should be continued and expanded. Non-Federal organizations that have established bi-lateral relationships and that can contribute significantly to the proposed policy issues include (in alphabetical order): Applied Technology Council (ATC), Building Research Institute (BRI) of Japan, California Universities for Research in Earthquake Engineering (CUREe), Earthquake

Engineering Research Center (EERC) at the University of California at Berkeley, Earthquake Engineering Research Institute (EERI), Japan Institute of Social Safety Science (ISSS), Japan Structural Consultants Association (JSCA), and National Center for Earthquake Engineering Research (NCEER). Consideration should be given to adding these organizations (not already belonging) to the membership of the UJNR Panel on Wind and Seismic Effects.

## V. Related Efforts

Policy issues relating to the assessment, repair, and rehabilitation of earthquake hazardous buildings relate closely to many of the other categories of policy issues to be considered during the first U.S./Japan Earthquake Policy Symposium. Closely related topics include seismic hazard zonation mapping at the national and regional scale; improved models for earthquake loss estimation; methods for quickly identifying areas most severely affected by damaging earthquakes; assessment and repair of lifelines, including associated building structures; performance based design standards, and analyses and laboratory testing of beam-column joints in steel moment frame buildings.

Particularly critical to the development and/or improvement of technologies for the assessment, repair, and rehabilitation of existing earthquake hazardous buildings are the ongoing efforts to reduce the earthquake hazards of steel moment frame buildings (see companion paper by R. D. Hanson). The discovery of severely damaged beam-column joints in more than 150 steel moment frame buildings following the 1994 Northridge, California, earthquake, the poor performance of steel moment frame buildings during the 1995 Kobe, Japan, earthquake, and the recent discovery of severely damaged beam-column joints in steel moment frame buildings in the San Francisco Bay area as a result of the 1989 Loma Prieta, California, earthquake, require immediate and focused investigations to determine how to properly repair such buildings and how to properly design new ones. Collaborative large- and full-scale testing of steel moment frame connections would be of immense benefit to both countries.

## VI. Key References

1. ATC, 1988, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*, prepared by the Applied Technology Council, Report No. ATC-21, Redwood City, California, published by the Federal Emergency Management Agency, Report No. 154, Washington, D.C.
2. ATC, in progress, *Guidelines for the Seismic Rehabilitation of Buildings*, prepared by the Applied Technology Council (Report No. ATC-33) for the Building Seismic Safety Council, to be published by FEMA, Report No. 273, Washington, D.C.
3. BSSC, 1992a, *Handbook for the Seismic Evaluation of Existing Buildings*, prepared by the Building Seismic Safety Council, based on a report prepared by the Applied Technology Council (Report No. ATC-22), published by FEMA, Report No. 172, Washington, D.C.



4. BSSC. 1992b. *Techniques for the Seismic Rehabilitation of Buildings*, prepared by the Building Seismic Safety Council. based on a report prepared by URS Consultants. San Francisco, published by FEMA. Washington, D.C.
5. FEMA. 1995. *National Mitigation Strategy: Partnership for Building Safer Communities*. prepared by the Federal Emergency Management Agency in support of the International Decade for Natural Disaster Reduction. Washington, D. C.